Dry Matter Yields of Cool-Season Grass Monocultures and Grass–Alfalfa Binary Mixtures

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ABSTRACT

Cultivars used in grass–alfalfa (*Medicago sativa* L.) mixtures for hay production in the semiarid Northern Great Plains have often lacked long-term productivity. This study was conducted to compare dry matter (DM) yields of grass monocultures and grass–alfalfa binary mixtures receiving annual applications of 0 and 50 kg N ha^{-1} over a 5-yr period. 'Reliant' and 'Manska' intermediate wheatgrass [*Thinopyrum intermedium* (Host) Barkw. and Dewey], 'Lincoln' smooth bromegrass (*Bromus inermis* Leyss.), 'Nordan' crested wheatgrass [*Agropyron desertorum* (Fisch.) Schult.], 'Lodorm' green needlegrass (*Stipa viridula* Trin.), and 'Dacotah' switchgrass (*Panicum virgatum* L.) were seeded in monoculture and in binary mixtures with 'Rangelander' alfalfa [*Medicago sativa* subsp. × *varia* (Martyn) Arcang.] on a Parshall fine sandy loam (coarse-loamy, mixed, superactive, frigid, Pachic Haplustolls) near Mandan, ND. Plant stands of green needlegrass and switchgrass were inadequate, and yields were not measured. Total seasonal DM yields from two cuttings averaged 8.74 and 2.71 Mg ha^{-1}, respectively, for grass–alfalfa mixtures and grass monocultures at 0 kg N ha^{-1}. At 50 kg N ha^{-1}, grass–alfalfa mixtures and grass monocultures averaged 8.72 and 5.04 Mg ha^{-1} DM yield, respectively. Yields of the grass component of first cut grass–alfalfa mixtures averaged 35% of total yield for intermediate wheatgrass, 33% of total yield for smooth bromegrass, and 30% of total yield for crested wheatgrass in the fifth production year. Cultivars included in this study, except those of green needlegrass and switchgrass, would be suited for use in binary grass–alfalfa mixtures for dryland hay production in the Northern Great Plains.

Legumes grown in mixtures with grasses provide advantages for hay production over grasses grown in monoculture. Many studies have documented that legumes complement grasses by increasing total seasonal yield and protein concentration of the herbage. Haynes (1980), in a comprehensive review of grass–legume associations, pointed out that legumes usually are able to obtain atmospheric N through symbiosis with N-fixing bacteria in amounts that are adequate for N nutrition of the legume. The percentage of N that is fixed by the legume and transferred to the grass component in hay production may vary from nil to 80% and occurs primarily through the decay of legume roots, nodules, or both (Brophy et al., 1987; Burity et al., 1989). Leyshon (1985), using the *difference method* for estimating N_2 fixation (Williams et al., 1971), concluded that alfalfa growing in association with grasses on a dryland site at Swift Current, SK, Canada fixed an average of approximately 40 kg N ha^{-1} yr^{-1}. Comparative data on differences between grass monocultures and binary grass–alfalfa mixtures are needed for DM yields over several years in response to N fertilization in the Northern Great Plains.

Alfalfa germplasm with a high proportion of its parentage from yellow flowering alfalfa [*M. sativa* subsp. *falcata* (L.) Arcang] and with the capacity to spread from new shoots arising from horizontal roots has demonstrated long-term persistence in the semiarid Northern Great Plains (Heinrichs, 1975; Berdahl et al., 1989). Other legumes, including cicer milkvetch (*Astragalus cicer* L.) (White and Wight, 1984) and sainfoin (*Onobrychis viciaefolia* Scop.) (Dubbs, 1971), had inferior persistence to hardy alfalfa germplasm at semiarid sites.

Results from earlier studies (Kilcher and Heinrichs, 1966; Kilcher et al., 1966) indicated that intermediate wheatgrass had poor persistence in mixtures with alfalfa relative to standard and fairway crested wheatgrass [*Agropyron cristatum* (L.) Gaertner] and smooth bromegrass. The intermediate wheatgrass used in these tests originated from common seed that had no cultivar designation. The recently developed intermediate wheatgrass cultivars Reliant (Berdahl et al., 1992) and Manska (Berdahl et al., 1993) were selected for long-term persistence and resistance to root rot (caused primarily by *Fusarium graminearum* Schwabe) and may be suited for use in grass–alfalfa mixtures in the Northern Great Plains.

Objectives of this study were to (i) compare DM yields of six grass entries grown in monoculture and in grass–alfalfa binary mixtures under two N fertility regimes and (ii) assess long-term persistence and productivity of two recently released intermediate wheatgrass cultivars relative to other grass species under these management treatments.

MATERIALS AND METHODS

The test was seeded 26 May 1993 at a dryland, rain-fed site near Mandan, ND that had a Parshall fine sandy loam soil (coarse-loamy, mixed, superactive, frigid, Pachic Haplustolls). The field site had been fallowed the previous season.

Dry matter yields were compared from 1994 through 1998 for four grass entries seeded in monoculture and in binary mixtures with Rangelander alfalfa, a cultivar noted for long-term persistence in the Northern Great Plains (Heinrichs et al., 1979). Treatments were randomized in a split-plot arrangement within a four-replicate, randomized complete block design. Whole plots consisted of grass–alfalfa mixtures with no N fertilizer, grass–alfalfa mixtures with annual applications of 50 kg N ha^{-1}, grass monocultures with no supplemental N, and grass monocultures with 50 kg N ha^{-1} annually. Nitrogen (NH_4NO_3) was broadcast during April in 1994 through 1998 on the designated whole-plot treatments. Nitrate-nitrogen in

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Abbreviation: DM, dry matter.

Table 1. Plant stands 1 yr. after seeding.

	Monoculture	Binary mixture	
Grass cultivar and species†	Grass	Grass	Alfalfa
	seedlings m^{-2}		
Reliant IWG	85	70	45
Manska IWG	95	72	46
Lincoln SB	94	70	50
Nordan CWG	85	56	53
Dacotah SG	102	15	57
Lodorm GNG	41	17	52
LSD (0.05)	17	19	11

† IWG, intermediate wheatgrass; SB, smooth bromegrass; CWG, crested wheatgrass; SG, switchgrass; and GNG, green needlegrass.

the top 30 cm of the soil profile averaged 62.5 kg ha^{-1} in 1993 when the study was initiated.

Subplot treatments consisted of Reliant intermediate wheatgrass, Manska intermediate wheatgrass, Lincoln smooth bromegrass (Hein, 1955a), Nordan crested wheatgrass (Hein, 1955b), Lodorm green needlegrass (Schaaf and Rogler, 1970), and Dacotah switchgrass (Barker et al., 1990). Lodorm and Dacotah did not produce adequate stands in grass–alfalfa mixtures (Table 1), and DM yields were not measured on subplots of these two grass entries. Each subplot consisted of three rows that were 6.1 m long with 38-cm row spacing. A single row of crested wheatgrass was sown between each plot to control intermingling of rhizomatous grasses from adjacent plots. Seeding rate was 100 pure-live seeds per lineal meter of row. The binary grass–alfalfa mixtures were seeded at 65 grass and 35 alfalfa seeds per lineal meter of row. Alfalfa seed was scarified and inoculated with *Rhizobium meliloti* before seeding. Seedling counts on one lineal meter of row of each subplot were made 16 May 1994. Soil water was measured gravimetrically in mid-May each year on four replicates of the Reliant–alfalfa–N subplot. Precipitation was recorded at a weather station located within 1 km of the test site.

Plots were harvested when alfalfa was in full bloom in mid-July of 1994, 1995, and 1996 and at early to mid-bloom in mid-June and mid-August of 1997 and 1998. Forage quality at these stages of plant development will be discussed in a subsequent paper. Each plot was trimmed to a 5.0-m length before harvest, and all three rows were harvested with a sicklebar mower to a stubble height of approximately 8 cm. Grass and alfalfa components from each subplot containing a binary mixture were hand-separated for the entire subplot from 1994 to 1996 and were separated from a subsample consisting of one linear meter of row per subplot in 1997 and 1998. All plots were mowed annually in October, including the establishment year of 1993, to a height of 10 to 15 cm to reduce effects of irregular snow cover across the study.

Data on total dry weight and dry weight of grass and alfalfa components were first analyzed separately by year using a split-plot ANOVA with effects from management practices (whole plots) and grass entries (subplots) considered fixed. Years were considered as random effects in a third split in the combined analysis over years (Steel and Torrie, 1980). Variances from Cut 1 and Cut 2 were not homogeneous according to Bartlett's test, and data from the two cuttings were analyzed separately. Whole-plot and subplot means were compared using an LSD (0.05) test. Statistical analyses were conducted using SAS procedures (SAS Inst., 1990).

RESULTS AND DISCUSSION

Plant stands of alfalfa and all grass mixtures except Dacotah switchgrass and Lodorm green needlegrass were adequate when measured in May 1994, 1 yr after seeding (Table 1). Dacotah switchgrass, the only C-4 species, had adequate stands in monoculture but did not compete with alfalfa during the establishment year. Lodorm green needlegrass did not have adequate establishment in either monoculture or binary mixture with alfalfa. Yield data were not measured on switchgrass

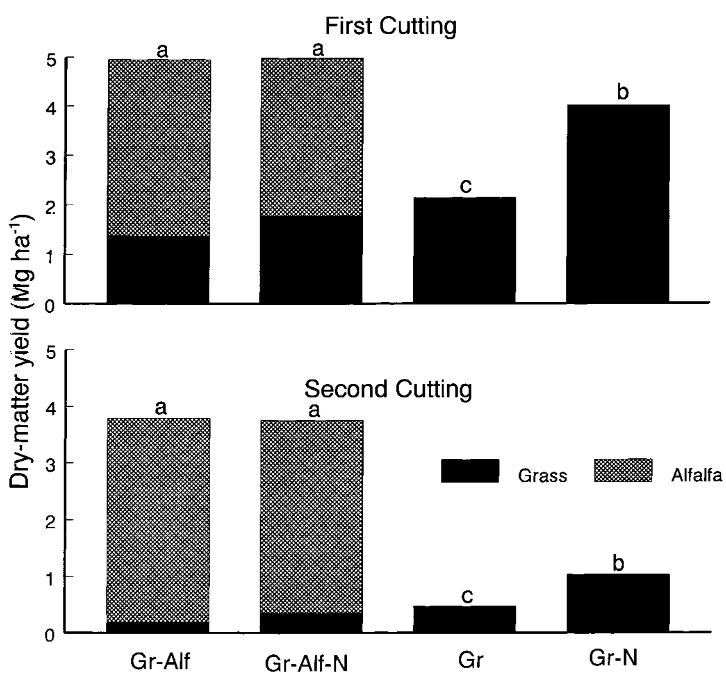

Fig. 1. Mean 5th- and 6th-yr dry matter yields of grass–alfalfa binary mixtures and grass monocultures at two cutting dates with 0 and 50 kg N ha^{-1} applied annually. Gr-Alf, grass–alfalfa mixture at 0 kg N ha^{-1}; Gr-Alf-N, grass–alfalfa mixture at 50 kg N ha^{-1}; Gr, grass monoculture at 0 kg N ha^{-1}; Gr-N, grass monoculture at 50 kg N ha^{-1}. Management treatments within cuttings that are followed by the same letter (a–c) are not significantly different (P = 0.05).

Table 2. Total first-cut dry matter yields of grass–alfalfa binary mixtures and grass monocultures grown at 0 and 50 kg N ha^{-1}.

Grass cultivar and species†	1994	1995	1996	1997	1998	Mean
	Mg ha^{-1}					
			Grass–alfalfa mixture, 0 kg N ha^{-1}			
Reliant IWG	9.85a‡	10.15a	7.49a	5.90a	4.25a	7.53
Manska IWG	9.15ab	9.32a	7.11ab	5.86a	4.09a	7.11
Lincoln SB	6.54c	7.56b	5.88b	5.65a	4.13a	5.95
Nordan CWG	7.79bc	8.05b	7.43a	5.64a	4.07a	6.60
			Grass–alfalfa mixture, 50 kg N ha^{-1}			
Reliant IWG	9.94a	11.95a	7.20a	6.21a	4.33a	7.92
Manska IWG	9.28ab	11.39a	7.84a	6.08a	4.36a	7.79
Lincoln SB	7.58c	9.48b	6.79a	5.96ab	3.67b	6.70
Nordan CWG	8.09bc	8.92b	6.86a	5.47b	3.81b	6.63
			Grass monoculture, 0 kg N ha^{-1}			
Reliant IWG	12.16a	10.41a	5.70a	2.78a	2.21a	6.65
Manska IWG	10.71a	9.19a	4.31ab	2.18ab	1.84a	5.65
Lincoln SB	6.00b	6.36b	3.63b	2.29ab	1.86a	4.03
Nordan CWG	4.35b	6.15b	3.70b	2.02b	1.94a	3.63
			Grass monoculture, 50 kg N ha^{-1}			
Reliant IWG	12.46a	12.47a	8.87a	5.32a	4.08a	8.64
Manska IWG	11.27a	12.13a	8.47a	5.06a	3.42b	8.07
Lincoln SB	6.01b	7.29c	5.50b	4.78a	2.97c	5.31
Nordan CWG	6.35b	8.76b	5.35b	4.08b	2.38d	5.38
Annual mean	8.60	9.35	6.38	4.71	3.34	

† IWG, intermediate wheatgrass; SB, smooth bromegrass; and CWG, crested wheatgrass.
‡ Means in a column within each management practice that are followed by the same letter are not significantly different ($P = 0.05$).

and green needlegrass plots. Kilcher et al. (1966) reported that established stands of green needlegrass in mixture with one other grass and alfalfa were maintained and were not unduly competitive with alfalfa during an 8-yr study at Swift Current, SK, Canada. Grass and alfalfa were seeded separately in perpendicular rows in the study conducted at Swift Current.

First- and second-cut yields averaged over all four grass cultivars in 1997 and 1998 indicated that these cool-season grasses make their major contribution to forage yield early in the season (Fig. 1). Grass contributed relatively little to overall yield in the second cutting of grass–alfalfa mixtures. Grass monocultures, even with supplemental N fertilization, produced lower DM yields than grass–alfalfa mixtures at both cuttings. Yields from grass monocultures were markedly lower than those from grass–alfalfa mixtures at the second cutting. For 1997 and 1998, DM yields of grass–alfalfa mixtures averaged 3.77 Mg ha^{-1} at the second cutting while those of grass monocultures averaged only 0.75 Mg ha^{-1}.

Supplemental N fertilizer did not increase total forage yields of the grass–alfalfa mixtures at either cutting, but the grass component was favored by N ($P = 0.05$). Wolf and Smith (1964), MacLeod (1965), Wedin et al. (1965), Kilcher (1966), and Nuttall et al. (1991) among others have reported, and it is generally accepted, that N fertilization stimulates the grass component of grass–alfalfa mixtures. In monoculture, grass yields were nearly doubled as a result of N fertilization in 1997 and 1998, the 5th and 6th yr after seeding (Fig. 1, Table 2). Power (1985) also reported that DM yields of seven grass species grown in monoculture were nearly doubled by annual applications of 45 kg N ha^{-1} over 9 yr at Mandan, ND. Significant grass entry × year interactions precluded the testing of means for differences. However, total yields from the first cutting clearly decreased following 1994 and 1995, the first 2 yr after establishment (Table 2). This may be accounted for in large part by available soil water. Even though early season precipitation was low in 1994 (Table 3), water had been stored in the soil from the previous season. In mid-May of 1994, 1995, 1996, 1997, and 1998, available water in the top 90 cm of the soil profile from four replicates of the Reliant–alfalfa–supplemental N treatment averaged 60, 115, 19, 23, and 14 mm, respectively. Total precipitation from April through June was below average in 1996, 1997, and 1998 when precipitation was crucial for high first-cut yields. Open-pan evaporation was never appreciably higher than the long-term average in any given month for the duration of this study (data not presented). Total open-pan evaporation from April through August ranged from 814 to 881 mm during the five production

Table 3. Precipitation for the duration of the study.

Month(s)	1994	1995	1996	1997	1998	124-yr avg.
	mm					
Total precipitation from previous Sept. to Apr. inclusive	74	300	125	208	123	129
Apr.	29	38	12	68	17	40
May	19	164	59	14	32	57
June	72	66	77	84	72	86
July	49	152	81	54	63	61
Aug.	5	43	44	27	113	47
Total	248	763	398	455	420	420

Table 4. First-cut dry matter yields of grass and alfalfa components in grass–alfalfa binary mixtures grown at 0 and 50 kg N ha^{-1}.

Grass cultivar and species†	1994 Grass	1994 Alfalfa	1995 Grass	1995 Alfalfa	1996 Grass	1996 Alfalfa	1997 Grass	1997 Alfalfa	1998 Grass	1998 Alfalfa	Mean Grass	Mean Alfalfa
	Mg ha^{-1}											
	Cut 1, 0 kg N ha^{-1}											
Reliant IWG	6.55a‡	3.30b	8.40a	1.76c	3.72a	3.77a	1.58a	4.32a	1.46a	2.80a	4.34	3.19
Manska IWG	6.15a	3.00b	7.04b	2.28c	3.14ab	3.97a	1.54a	4.25a	1.17a	2.93a	3.82	3.29
Lincoln SB	2.41b	4.13b	3.67c	3.89b	1.89b	3.99a	1.25a	4.44a	1.47a	2.67a	2.13	3.82
Nordan CWG	1.60b	6.19a	1.92d	6.13a	2.29ab	5.14a	1.09a	4.39a	1.22a	2.85a	1.66	4.94
	Cut 1, 50 kg N ha^{-1}											
Reliant IWG	6.84a	3.09b	10.86a	1.08bc	3.98ab	3.21a	2.68a	3.54a	1.64a	2.68a	5.20	2.72
Manska IWG	6.48a	2.80b	10.59a	0.79c	5.22a	2.62a	1.70c	3.65a	1.67a	2.70a	5.28	2.51
Lincoln SB	3.83b	3.75b	7.68b	1.80b	3.74ab	3.06a	2.38ab	3.97a	1.09b	2.58a	3.66	3.03
Nordan CWG	2.48b	5.60a	4.22c	4.69a	3.01b	3.84a	2.01bc	3.83a	1.12b	2.69a	2.50	4.13

† IWG, intermediate wheatgrass; SB, smooth bromegrass; and CWG, crested wheatgrass.
‡ Means in a column within each N treatment that are followed by the same letter are not significantly different (P = 0.05).

years of this study compared with a 20-yr average of 895 mm for these months at Mandan, ND.

Total first-cut yields of grass–alfalfa mixtures were highest for treatments that included the two intermediate wheatgrass cultivars during the first two to three production years of the study (Table 2). In the grass–alfalfa mixtures with no N fertilizer, total first-cut yields were not statistically different (P = 0.05) among grass entries in 1997 and 1998. With supplemental N fertilizer, total yields of the mixtures that included intermediate wheatgrass remained high, relative to other grass cultivars, for the duration of the study. In grass monocultures with supplemental N, the two intermediate wheatgrass cultivars, Reliant and Manska, had higher first-cut yields than Lincoln smooth bromegrass and Nordan crested wheatgrass (Table 2). Differences in yields among the grass entries diminished toward the end of the 5-yr period, particularly in monocultures that received no supplemental N. Reliant averaged slightly higher yields than Manska in all annual comparisons, but these differences generally were not statistically significant.

In 1996, the 4th yr after seeding, alfalfa accounted for a slightly higher proportion of the first-cut yields than intermediate wheatgrass for the first time in grass–alfalfa mixtures that received no N fertilizer (Table 4).

Table 5. Second-cut dry matter yields of grass and alfalfa components in grass–alfalfa binary mixtures grown at 0 and 50 kg N ha^{-1}.

Grass cultivar and species†	1997 Grass	1997 Alfalfa	1998 Grass	1998 Alfalfa	Mean Grass	Mean Alfalfa
	Mg ha^{-1}					
	Cut 2, 0 kg N ha^{-1}					
Reliant IWG	0.24a‡	3.78b	0.17a	3.44a	0.21a	3.61a
Manska IWG	0.19a	3.91ab	0.15a	3.25ab	0.17a	3.58a
Lincoln SB	0.25a	4.06a	0.16a	3.17b	0.20a	3.61a
Nordan CWG	0.19a	3.97ab	0.15a	3.20b	0.17a	3.59a
	Cut 2, 50 kg N ha^{-1}					
Reliant IWG	0.51ab	3.99ab	0.28a	2.94a	0.39ab	3.46ab
Manska IWG	0.38bc	3.87b	0.16b	2.77ab	0.27c	3.32ab
Lincoln SB	0.65a	4.19a	0.21ab	2.83ab	0.43a	3.51a
Nordan CWG	0.29c	3.94ab	0.29a	2.64b	0.29bc	3.29b

† IWG, intermediate wheatgrass; SB, smooth bromegrass; and CWG, crested wheatgrass.
‡ Means in a column within each N treatment that are followed by the same letter are not significantly different (P = 0.05).

Alfalfa dominated the intermediate wheatgrass–alfalfa mixtures in subsequent years. McCloud and Mott (1953) reported that legumes yielded more than smooth bromegrass for the first time during the third growing season in grass–legume mixtures that received no supplemental N. They attributed the reduced yields of smooth bromegrass, relative to three legume species, to the depletion of soil N. In our study, grass–alfalfa mixtures that received 50 kg N ha^{-1} annually were still dominated by grass in 1995. The exception was Nordan crested wheatgrass, which yielded less than alfalfa in all test years. In 1997 and 1998, the alfalfa component was higher yielding than grass in all grass–alfalfa mixtures. The shift in the proportion of alfalfa may have been caused by an inadequate supply of soil N for the grass component of the mixtures.

Grass cultivars did not differ in second-cut yields when grown in grass–alfalfa mixtures with no N fertilizer (Table 5). Reliant intermediate wheatgrass and Lincoln smooth bromegrass averaged higher second-cut grass yields than Manska intermediate wheatgrass (P = 0.05) in grass–alfalfa mixtures fertilized at 50 kg N ha^{-1}, but all grass yields were low relative to alfalfa. With no N fertilizer, the ratio of grass to alfalfa DM yield was 1:19, and with 50 kg N ha^{-1}, the ratio was 1:10. The contribution of alfalfa to total DM yield in both cuttings was remarkably stable in 1997 and 1998 after alfalfa dominated the mixtures (Tables 4 and 5). With no supplemental N, total seasonal yield for both cuttings averaged over 1997 and 1998 was 8.74 and 2.71 Mg ha^{-1}, respectively, for grass–alfalfa mixtures and grass monocultures, a 223% increase for mixtures over the grass monocultures. With 50 kg N ha^{-1}, grass–alfalfa mixtures and grass monocultures averaged 8.72 and 5.04 Mg ha^{-1}, respectively, a 73% increase for grass–alfalfa mixtures over grass monocultures.

Grass made its major yield contributions in mixtures during the first three production years; thereafter, alfalfa produced more yield than grass in all grass–alfalfa mixtures (Table 4). Without N fertilization, first-cut yields of grass monocultures were similar to those of grass–alfalfa mixtures for only 2 yr; thereafter, the grass–alfalfa mixtures were clearly superior in yield (Table 2). Hay yields of grass–alfalfa mixtures were much greater than grass monocultures in those years when midsummer precipitation was adequate for a second cutting (Fig. 1 and Table 5). For dryland hay production in a semiarid region, Kilcher and Heinrichs (1966) and Dubbs (1971) have stressed the importance of using a hardy alfalfa cultivar with substantial fall dormancy and perhaps a spreading growth habit in mixture with a grass cultivar that is not unduly competitive with alfalfa. None of the cultivars included in the present study were unduly competitive with alfalfa, and the recently released intermediate wheatgrass cultivars, Reliant and Manska, had adequate persistence. Alfalfa, intermediate wheatgrass, crested wheatgrass, and smooth bromegrass cultivars in the present study would be suited for use in binary grass–alfalfa mixtures for dryland hay production in most subhumid to semiarid portions of the Northern Great Plains.

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